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Laser-Induced Bleaching of Carbon Nanomaterials Suspensions

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We have studied the effect of nanosecond laser pulses on the optical properties of onion-like (OLC) and multi-wall carbon nanotubes (MWNTs) suspensions in *N,N*-dimethylformamide (DMF). The results demonstrate that both suspensions irreversibly bleach under high-intensity laser radiation. The bleaching is accompanied by losing optical limiting (OL) in suspensions.

Keywords: Onion-Like Carbon, Multi-Wall Carbon, Optical Limiting, Suspension, Bleaching.

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1. INTRODUCTION

The laser radiation interaction with suspensions of various carbon nanoparticles is of interest for the development of optical limiters and passive laser switches intended to protect light sensors and human eyes from optical damage [1-4]. In contrast to fullerene solutions [5], suspensions of OLC and MWNTs have a broad absorption band [6, 7]. At the same time our experiments have shown the suspensions of OLC and MWNTs in DMF to be sufficiently stable in contrast to the similar aqueous suspensions [6]. This makes such suspensions potentially attractive for the development of broadband optical limiters. In this paper we summarize the studies of laser radiation effect on optical properties of the suspensions of OLC and MWNTs in DMF [7, 8].

2. EXPERIMENTAL

2.1 OLC suspension

OLC samples were prepared by annealing detonation nanodiamond particles in vacuum at 1800 °K [9]. Annealing leads to nanodiamond graphitization and conversion to OLC. The OLC powders were dispersed in DMF by sonication. The suspension with an OLC concentration of 1 mg/ml was found to be stable. The average size of the OLC agglomerates was about 170 nm as determined by photon correlation spectroscopy (PSS Nicomp 380/ZLS instrument). The transmission electron microscopic (TEM) image of the OLC sample is shown in the Fig. 1a.

The suspension was injected into an optical cuvette and affected by the laser pulses, with the duration of 20 ns and the wavelength of 1064 nm.

2.2 MWNTs suspension

The MWNTs were produced by the CVD technology in the reaction of ethylene thermal decomposition on the Fe/Co catalysts. Its average diameter and length were 7-9 nm and 10-20 µm, respectively. Synthesized MWNTs contained impurities of iron on account of the Fe/Co catalyst used, hereupon, the bundles of MWNTs possessed paramagnetic properties that revealed itself in their feature of attracting to one or the other constant magnet pole. The stable suspension of MWNTs in DMF was obtained using ultrasonic dispersion. The MWNTs concentration was 0.015 g/l. The TEM image of MWNTs is shown in Fig. 1b.

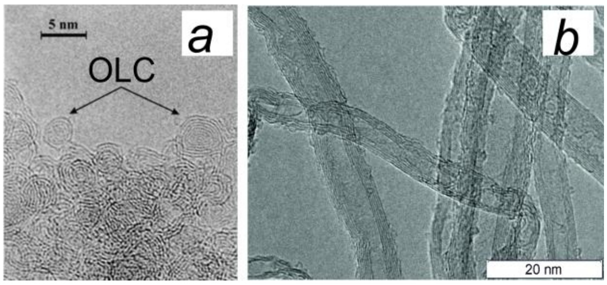

Fig. 1 – TEM images of OLC sample (a) and MWNTs sample (b). The dark lines represent projections of graphene shells perpendicular to the image plane.

The suspension was injected into an optical cuvette and affected by the laser pulses, with the duration of 17 ns and the wavelength of 532 nm.

3. RESULTS AND DUSCUSSION

The transmittances of the cuvettes with studied suspensions $\tau = E_{out}/E_{in} \times 100$ % (where E_{out}, E_{in} are the energies of transmitted and incident pulse, respectively) are presented in Figure 2a,b. These curves illustrate that after a certain number of laser shots the irradiated zones of both suspensions become essentially transparent. At the same time the first laser pulses experience optical limiting in both suspensions, however, after the suspensions treatment by a large number of laser pulses the suspensions bleach and cease to absorb the incident radiation in the laser beam area.

Though the suspensions lose optical limiting, with the small bleached part moving upward due to the

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thermal convection, they can operate as the OL. Thereto it is necessary for the non-bleached portion of the suspension to get into the interaction area after each laser flash. It is evident that it can be realized by simple suspension mixing, but can also be put into effect by another way. It was mentioned above that MWNTs obtained possess paramagnetic properties, with the motion of the nanotubes particles bundles in the field of constant magnet being observed by an unaided eye in the non-dispersed suspension. It was also established that bleached fraction of the OLC suspension possess pronounced diamagnetic properties (initial OLC suspension did not possess such properties) that reveals itself in the motion of the bleached fraction in the non-uniform magnet field as a diamagnetic particle. So it was possible to initiate the both suspensions motion by a field effect of a constant magnet situated near the cuvette in certain way.

It is clear that the chaotic motion of the suspension elements can be initiated by other methods, such as a nonuniform heating of the cuvette with the suspension. However, the technique described allows the suspensions to operate as optical limiters without contact with the heater elements.

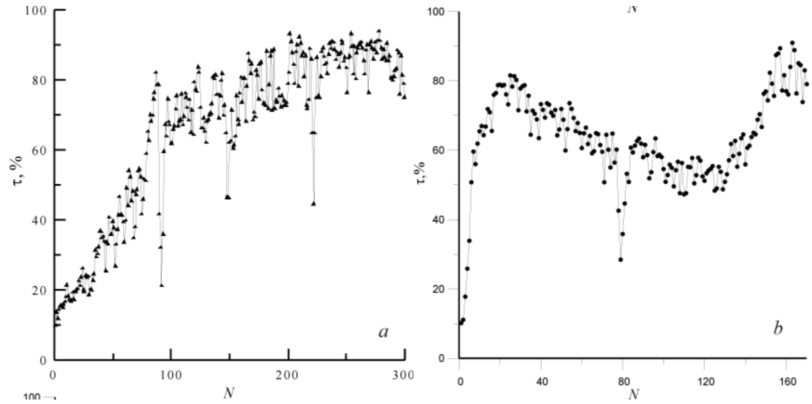

Fig. 2 – Transmittance τ of the OLC (a) and MWNTs (b) suspensions in DMF as a function of N at laser pulses energies of 0.5 mJ and 0.079 mJ, respectively.

4. CONCLUSION

The results presented demonstrate that high-power nanosecond laser pulses have a significant effect on optical properties of OLC and MWNTs suspensions in DMF. The optical limiters and passive laser switches based on the phenomenon of laser-induced bleaching in these suspensions can be designed.

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